OPTIMAL ECONOMIC AND EMISSION DISPATCH OF PHOTOVOLTAIC INTEGRATED POWER SYSTEM USING FIREFLY ALGORITHM

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Special dedication to my beloved father and mother

MUHAMAD SALIM BIN OMAR and Almarhumah KHAMASAH BINTI ABDULLAH

And to all my siblings,

Saifullah Bin Muhamad Salim

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Thank you for your prayers, support, guidance and love.

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ABSTRACT

The main purpose of Economic Load Dispatch (ELD) is to determine the optimal output of generating units to meet the power demand at lowest possible cost and subjected to the operational constraints. Various ELD optimization methods have been developed in order to deal with the challenges of continuous and sustainable power at optimal cost. The deficiency of fossil fuel reserve and rapid increase of fuel prices to generate electricity has encouraged the use of Renewable Energy (RE). Furthermore, concerns over environmental pollution also become a factor to incorporate the RE and fossil fuel in generating electricity. This project propose the Firefly Algorithm (FA) to solve Economic and Emission Load Dispatch (EELD) problems that consists of photovoltaic systems. The FA algorithm is used to determine the optimal cost and emission levels of power generation. The test case considered in this project is Static Combined Economic and Emission Dispatch (SCEED) that been simulated for each hour. The test system with 6 units of thermal generator and 13 units of PV generator are used to optimize SCEED problem by using FA. The Weight Sum Method (WSM) approach is used to determine the best compromise solution among the cost and emission. It found that FA can provide the fast convergence in finding the global minima value. It can be concluded that FA can solve the problem of economic and emission dispatch accurately.

ABSTRAK

Tujuan utama *Economic Load Dispatch* (ELD) adalah untuk menentukan keluaran optimum unit penjanaan bagi memenuhi permintaan kuasa dengan kos yang paling rendah dan tertakluk kepada kekangan operasi. Pelbagai kaedah penyelesaian masalah ELD telah dibangunkan untuk menangani cabaran kuasa berterusan dan berkekalan pada kos yang optimum. Kekurangan rizab bahan api fosil dan peningkatan pesat harga bahan bakar untuk menjana tenaga elektrik telah menggalakkan penggunaan tenaga boleh diperbaharui (RE). Tambahan lagi, kebimbangan terhadap pencemaran alam sekitar juga menjadi faktor yang menggabungkan sumber tenaga RE dan bahan api fosil dalam penjanaan elektrik. Projek ini mencadangkan penggunaan *Firefly Algorithm* (FA) untuk menyelesaikan masalah *Economic Emission and Load Dispatch* (EELD) yang mengandungi sistem fotovolta. Algoritma FA digunakan untuk menentukan kos dan tahap pelepasan gas yang optimal. Kes ujian yang dipertimbangkan ialah SCEED yang disimulasikan untuk setiap jam. Sistem ujian ini mempunyai 6 unit penjana haba dan 13 unit penjana PV yang digunakan untuk mengoptimuman masalah SCEED dengan menggunakan kaedah FA. Kaedah *Weight Sum Method* (WSM) digunakan untuk menentukan penyelesaian kompromi terbaik antara kos dan pelepasan gas. Ia mendapati bahawa FA boleh menghasilkan penumpuan yang cepat dalam mencari nilai minima global. Dapat disimpulkan bahawa FA boleh menyelesaikan masalah SCEED dengan tepat.

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LIST OF SYMBOLS AND ABREVIATIONS

α	-	Temperature Coefficient
m	-	Number of Solar Panel
n	-	Number of Thermal Generator
P_{imin}	-	Minimum Power Limits
P_{imax}	-	Maximum Power Limits
P_{rated}	-	Rated Power
S_i	-	Incident Solar Radiation
T_{ref}	-	Reference Temperature
T_{cell}	-	Cell Temperature
μ	-	Membership Function
ACO	-	Ant Colony Algorithm
ALO	-	Ant-Lion Algorithm
CO_X	-	Carbon Oxides
EELD	-	Economic and Emission Load Dispatch
ELD	-	Economic Load Dispatch
EP	-	Evolutionary Programming
FA	-	Firefly Algorithm
FDM	-	Fuzzy Decision Making
GA	-	Genetic Algorithm
KHA	-	Krill Herd Algorithm
MPP	-	Minimum Power Performance
NO_X	-	Nitrogen Oxides
PSO	-	Particle Swarm Optimization
RES	-	Renewable Energy Sources
SCEED	-	Static Combined Economic and Emission Dispatch
SO_X	-	Sulfur Oxides
WSM	-	Weight Sum Method

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CHAPTER 1

INTRODUCTION

1.1 Introduction

To generate electricity, electrical power generation system largely depends on fossil fuel that powered by thermal plant [1]. According to the expert, the fossil fuel reserves are limited and may be run out within 2050 [2]. During the period of 1990 to 2016, more than 90% of electricity generated for peninsular Malaysia was attained from fossil fuel. In 2016, 52% of the electrical energy generation is provided by coal while gas contributed 44% [3]. A large percentage of electricity generation is produced by coal and natural gas. The availability of fossil fuels such as oil, coal and natural gas is decreasing day by day and power demand is increasing. The cost of the fossil fuel is being increased which is creating a bigger problem [4]. An optimization and controlled action must be taken to reduce the possibility of fossil fuel declining.

There are many alternative way to generate electricity such as hydropower, bio energy, solar energy, wind energy and tidal energy. However, fossil fuel stills remain as a main sources to generate electricity [1]. In Turkey, renewable energy generation has contributed 6% to the total generation in 2015. They expecting the proportion of renewable energy generation been grown at least 30% in the total amount of energy generation in 2023 [5]. Malaysia is well endowed with abundant non-renewable and renewable sources of energy, especially biomass and solar [6]. Country has set an ambitious target for 20% of country's electricity be generated from renewable sources by 2030 [7].

Nevertheless, fossil fuel is still be a main source of generating power electricity in Malaysia. The pollutant gas emission created during combustion fossil fuel that caused an air pollution. Environmental concerns have placed investment in low-carbon power generation technologies as one of the priorities of the energy agendas of many countries around the world [5]. The problem of pollutant gas emission that cause environment pollution also motivate a researcher to work on minimizing the use of fossil fuel in thermal plant during the process of electricity generation [1].

Economic Load Dispatch (ELD) problem relates to the optimum generation power system to minimize fuel cost while to satisfy the load demand and operational constraint [8]. ED with both cost and emission minimization becomes a multi objective optimization problem and is named as Combined Economic and Emission Dispatch (CEED) [9]. In solving CEED problem, Fuzzy Based Mechanism and Weighted Sum Method (WSM) used to find best compromise solution. The test cases that has been considered is Static Combined Economic and Emission Dispatch (SCEED). SCEED is performed for full solar radiation level as well as for reduced radiation level and it was been simulated by single hour [9].

Firefly Algorithm is widely used by previous researcher for solving economic and emission load dispatch considering thermal generators. However, less researcher solve the economic problem with both thermal and photovoltaic generators. Firefly Algorithm (FA) has been developed by Xin She Yang in 2008 that based on the movement of flashing behavior of firefly as an idea. All fireflies are unisex and they will move towards more attractive and brighter ones without considering their gender [10]. The advantages of firefly algorithm is flexibilities and using simple concept where it depend on communication of the swarming particles [11].

1.2 Problem statement

The major worldwide source of electricity is generated by fossil fuel. The increasing of prices, environmental concern, and rapid depletion of fuel reserves have been expanding the scope of renewable energy resources [9]. The fossil fuel reserves are limited and may be run out within 2050 [2]. Optimization solutions are required to minimize both fossil fuel pollutant emission and cost. The main source of generating power electricity in Malaysia is fossil fuel. Malaysia has targeted to reduce the carbon emission intensity by 40% by the year 2020 and 45% by the year 2030 [3] [12]. However, the deficiency of fossil fuel reserve and rapid increase of fuel prices to generate electricity has encouraged the use of Renewable Energy (RE). Furthermore, concerns over environmental pollution also become a factor incorporate the RE and fossil fuel in generating electricity. The solar power is one of the renewable energy that reliable in Malaysia and this initiative can help on fuel optimization. With the use of photovoltaic technologies can help system to reduce an emission. This project propose a Firefly Algorithm technique to minimize both cost and emission of power generating considering on photovoltaic system.

1.3 Objective

The main objective is focus on solving cost and emission problem on thermal and photovoltaic power generation. This project will be conducted based on the following objectives:

i. To formulate economic and emission load dispatch problem for thermal and photovoltaic power generation.
ii. To develop Firefly Algorithm in order to optimize cost and emission of thermal and photovoltaic generating units for 24 hours.
iii. To analyze the performance of Firefly Algorithm on cost, emission and time to simulate using MATLAB software.

1.4 Scope of Study

This project primarily use Firefly Algorithm method to investigate a problem related to optimal economic and emission in power generation. The scope of this project as follows:

i. The consider case study consist of 6 units of thermal and 13 units of photovoltaic generating units that considering power generation and emission problems.
ii. MATLAB R2019a software used to identify a result of economic emission dispatch problem.
iii. Performance of Firefly Algorithm investigated in terms of convergence, robustness and minimization of cost and emission.
iv. The investigation of power dispatch problem for 24 hours.

1.5 Report Outline

Chapter 2 focusses on the economic and emission load dispatch of power generation of thermal and photovoltaic and the method used which is Firefly Algorithm. All previous methods are discussed in this chapter.

Chapter 3 explains the methodology of this project and problem formulation of economic and emission dispatch of power thermal and photovoltaic power generation using Firefly Algorithm.

Chapter 4 discusses the finding of the project. The result are analyze to investigate the performance of the case study in terms of robustness, effectiveness and optimization.

Chapter 5 concludes the main finding obtained by this chapter also provide the recommendation for future work.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter focuses on the literature review of economic and emission dispatch problem. Several papers have been reviewed about power dispatch with PV in this chapter. Optimization method can be categorized into three parts which are classical methods, non-conventional method and hybrid methods. This chapter describes about economic load dispatch, emission load dispatch, combined economic and emission dispatch, photovoltaic, optimization method, and Firefly Algorithm.

2.2 Economic Load Dispatch (ELD)

Economic load dispatch (ELD) is an optimization problem that allocates power to each committed generating unit so as to minimize the total operational cost, subject to constraint [9]. ELD is use to determine the minimum output power that generate by power generation for the system load and operate the generator at minimum fuel cost [13]. The main purpose of ELD is to arrange the power system control variables for sharing the total load to achieve highest economy of operation. All the equality and inequality constraint must be satisfied [14]. Due to fuel cost and power demand increase, economic dispatch problem become an important issues [15]. In realistic operation should consider valve point effect, multiple fuels, and ramp rate to achieve the optimal solution of ELD [14].

The input output cost curve of a thermal generating unit is obtained by multiplying cost per unit heat and its input output heat rate curve [9]. Figure 2.1 shows the total generation cost against the power output in each generator. The power output is limited by the minimum (P_{Gmin}) and maximum (P_{Gmax}) capacity of the generating units.

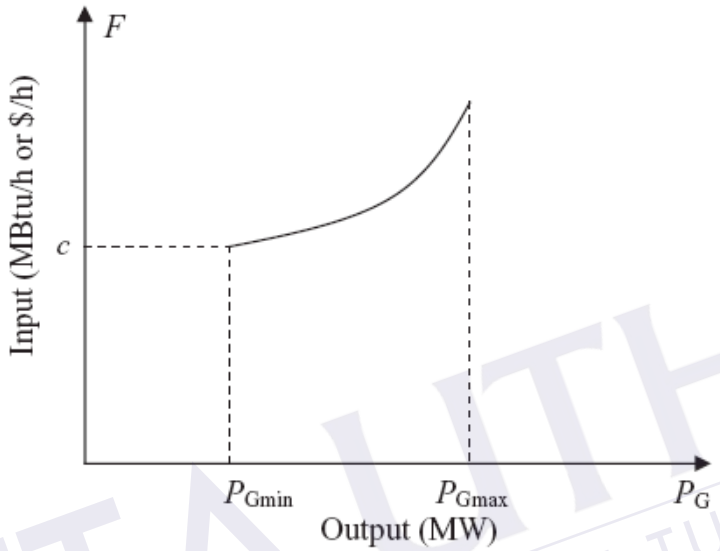

Figure 2.1: Cost characteristic of the thermal generating unit

2.2.1 Cost Function

The generation cost function is expressed in quadratic polynomial or piecewise functions form [16]. Figure 2.2 shows a non-smooth electrical energy cost function considering multiple valve-point effect [16].

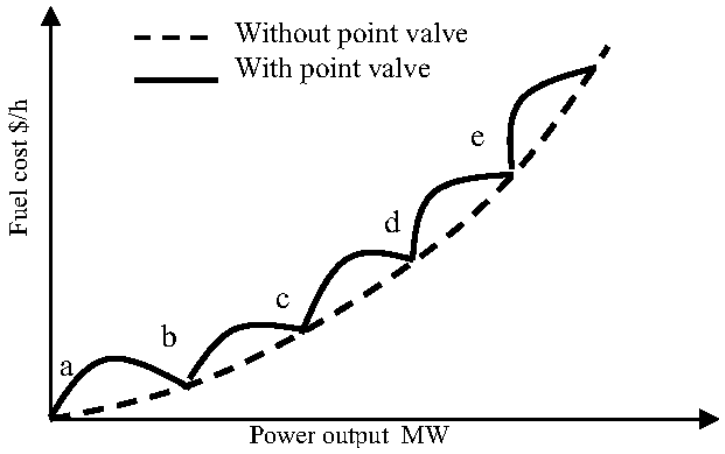

Figure 2.2: Cost function of a thermal unit with and without valve-point

The bold-line is generated to consider the valve-point effects. The dotted-line increase in losses causing wire drawing effect result in phenomena [17].

2.3 Economic and Emission Load Dispatch (EELD)

Power generation from fossil fuels combustion causes hazardous gases to emitted, which pollutes the air and causes significant and long term damages on the environment [1]. Economic emission load dispatch deals with the minimization of the cost and emission of hazardous gases and particulates from the combustion system [1]. Fossil fuel emit the emission of pollutant like Nitrogen Oxides (NO_x), Sulfur oxides (SO_x), Carbon Oxides (CO_x), particulate matters, from the thermal power plant [18]. Research on renewable energy efficiency, CO_2 emissions and economic growth is become significant in climate change mitigation, and economic benefits. Hence, this fact has motivates researches to work on minimizing the use of fossil fuel in the thermal plant during the process of electricity generation [1]. Hamzacebi and Karakurt stated that the amount of CO_2 emissions will increase of 64% growth in 2025 [19]. The emission can be reduced by proper load allocation among the various generating units of the plant [13].

2.4 Combined Economic and Emission Dispatch (CEED)

Combined Economic and Emission Dispatch (CEED) is a multi–objective optimization problem that used to minimize both cost and emission of power generation [9]. A multi objective CEED problem considering all practical constraints including ramp rate limits, POZs, valve loading effect, multi-fuel options spinning reserve and transmission losses to describe the performance of proposed method [20]. CEED is one of technique to compute the optimal generation of the power system by minimizing the fuel cost and emission levels simultaneously. Until now lot of various optimization have been conducted in solving CEED problem [21]. This is done by creating combining economic and emission formulation with the help of parameter called "penalty factor". The lower the value of the penalty factor, the value of the CEED will be less [22]. The test case that has been considered is Static Combined Economic and Emission Dispatch (SCEED). SCEED is performed for full solar radiation level as well as for reduced radiation level and it was been simulated by single hour.[9].

2.5 Photovoltaic power generation (PV)

The development and Renewable energy sources (RES) has been encouraged according to the Global warning and the critical depletion of fossil fuel over the few past decades. Until days, solar energy becomes famous on generating power for residential, commercial and industrial application because it was a promising source in generate electricity [23]. Photo-voltaic power generation have a higher overall efficiency compared to the other renewable energy [24]. Solar PV is used in stand-alone and grid-connected systems to supply power to end user. Due to the essential role in generating electricity, the size of solar PV plant has grown rapidly [23]. The main countries which implement photovoltaic distributed generation (DG) subsidy policies are England, Germany, Australia, Italy, japan, and others [25].

Net Energy Metering (NEM) has annual power generation capacity of 100MW. The 90MW of annual capacity is for Peninsular Malaysia while 10MW is for Sabah and Labuan. This has been set for five years, from 2016 to 2020. Which means that if

take-up is maximized each year, a total of 450MW of electricity will be generated from solar PV in Peninsular Malaysia by the year 2020 [3].

PV has several disadvantages such as PV modules exposed to hot and humid climates show considerably higher degradation modes than those in desert and moderate climates. The degradation modes and degradation rates of thin-film PV modules exposed to relatively dry and sunny climate in Spain. Observed degradation modes include material corrosion, delamination, discoloration of en-capsuling over cells, and breakage of cracks of modules. These degradation modes affect the PV characteristic in three ways: decreasing transmittance τ, increasing series resistance, R_s and decreasing shunt resistance, R_p [26].

2.6 Optimization Methods

There are two categories of optimization methods which are classical method and meta-heuristic optimization method [20]. Some researchers have combine two or more algorithms to achieve superior performance compare to the stand alone methods in order to solve CEED problems [1]. Optimization techniques have been employed to solve the generation scheduling problem [27]. The classic method such as lambda iteration [15], gradient method, integer programming, quadratic programming, and linear programming [28]. Modern heuristic optimization methods are proposed by researcher based on artificial intelligence concepts such as Evolutionary Programming (EP), Genetic Algorithm (GA), Hopfield Neural Network, Particle Swarm Optimization (PSO) [29], Ant Colony Algorithm (ACO), Ant-Lion Algorithm (ALO), Krill Herd Algorithm (KHA), and Firefly Algorithm (FA) [30].

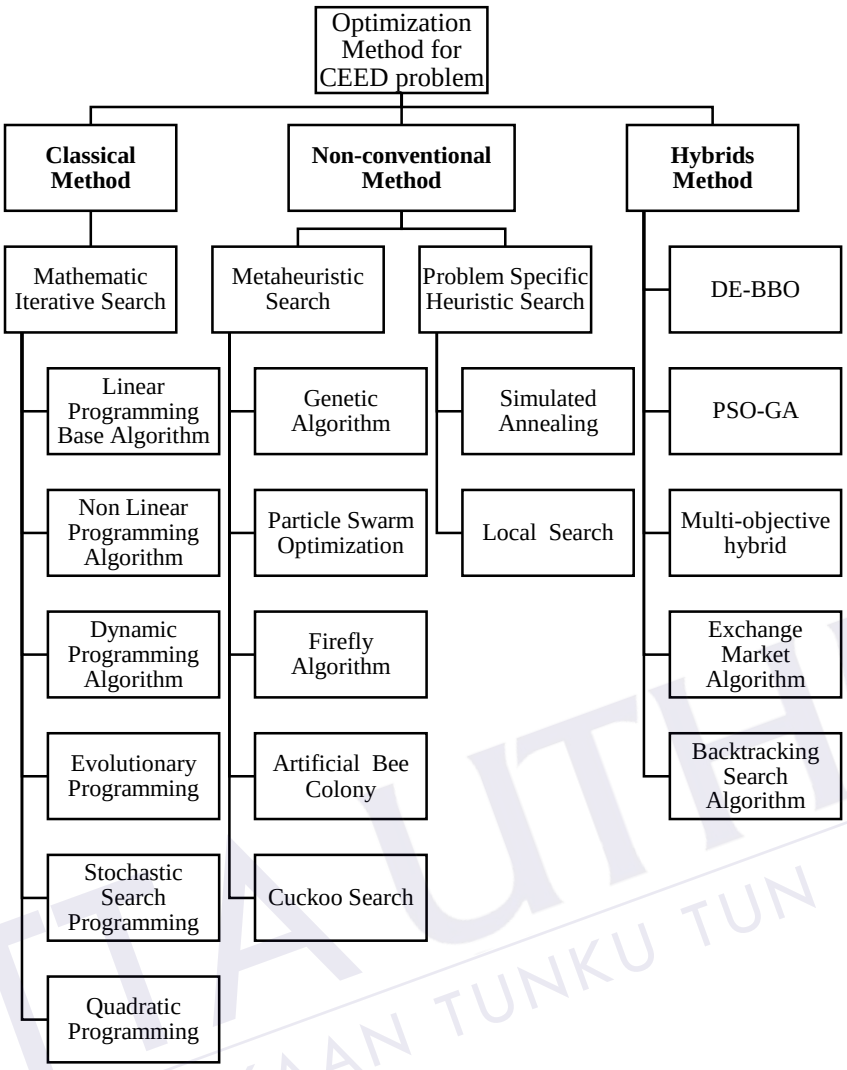

Figure 2.3: Type of optimization methods

All of three types of optimization have their own advantages and disadvantages. Table 2.1 shows the advantages and disadvantages of these methods.

Table 2.1: Advantages and Disadvantages of Optimization Methods

Methods	**Advantages**	**Disadvantages**
Classical methods	1. Able to find the local maximum and minimum objective function efficiently [13].	1. Slow convergence rate when implemented to large scale problem.
Non-conventional methods	1. Effectively used to solve non-linear and non-continuous optimization problems [21]. 2. Able to generate high-quality solutions within shorter calculation time and stable convergence characteristic [13].	1. The mutation operator is adding a randomly generated number to a parameter of an individual of the population [22]. 2. The sensitive parameters setting can cause wrong calculation and affect the

Methods	Advantages	Disadvantages
		algorithm performance of the solutions [31].
Hybrids methods	1. Able to solving complex problems [32].	1. Limited to solving single optimization problems [32].

2.7 Firefly Algorithm (FA)

Firefly Algorithm (FA) has been developed by Xin She Yang in 2008 at Cambridge University [33], based on the flashing patterns and behavior of fireflies. In the firefly algorithm, the objective function of a given optimization problem is associated with this flashing light or light intensity which helps swarm of fireflies to move to brighter and more attractive locations in order to obtain efficient optimal solutions [10]. Firefly Algorithm has two superiorities: automatic subdivision and random reduction. The fireflies can automatically divide into subgroups so that these subgroups swarm around the multimodal optimal and make it possible for the algorithm to find all global optimal simultaneously [34]. Fireflies produce the short rhythmic patterns of flashing light to attract their partners and these patterns of flashes are unique in species to species through a bioluminescence process [11]. The firefly algorithm can formulize two importance issues which are light intensity and the attractiveness. For distance, the Cartesian function is used to define the distance between any two fireflies at their different position. The movement of firefly can be calculate based on the certain equation.

There are three idealized rules are defined to characterize firefly [35].

i. All fireflies are unisex and they move towards the more attractive and brighter one without considering their sex.
ii. The level off attraction of firefly is proportional to brightness which reduces with the increase in the distance between two fireflies since air absorbs the light.
iii. The brightness or light intensity is determined by the value of the objective function of a given problem and it is proportional to the light intensity for maximization problem.

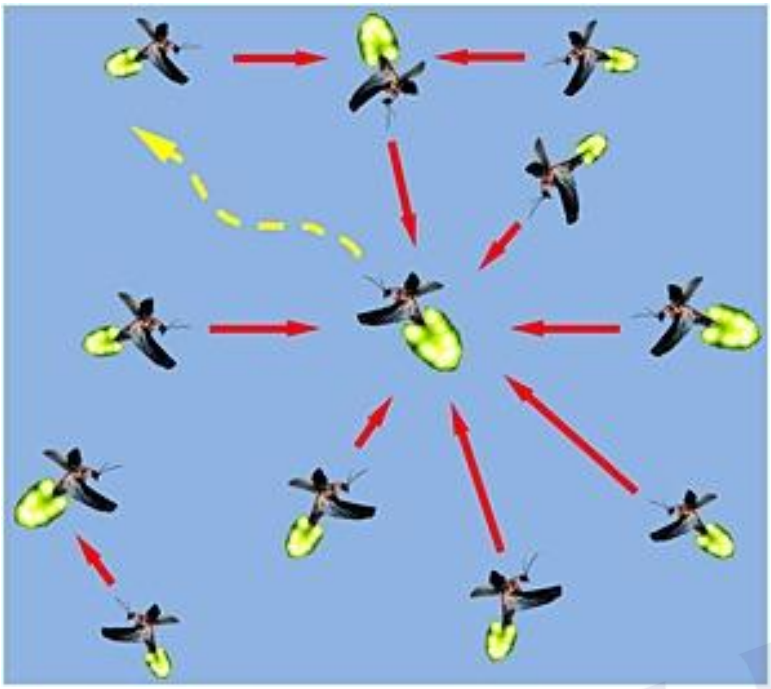

Figure 2.4: The behavior of firefly move to brightest

2.8 Review of power dispatch with photovoltaic

Table 2.2 shows the power dispatch with photovoltaic that has been analyze. This table consists of problem, algorithm and test system.

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